COPING WITH CLIMATE CHANGE IN AGRICULTURE: A PORTFOLIO ANALYSIS

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Abstract

Potential impact of climate change on crop production in The Netherlands is explored at farm level by means of a whole farm portfolio analysis. Projected joint crop yield distributions were derived from crop growth models, whereby the projected impact of weather conditions was compared with historic data. A typical Dutch arable farm with potatoes, sugar beet and winter wheat on poor sandy soils was analysed in accordance with sets of historic and projected weather conditions. Projected crop yields and ultimately farm income increased due to more favourable climate conditions, even when the risk of poor performance of a particular crop due to extreme weather conditions increases. Commonly expressed expectations as to increased risk of crop failure and income loss due to climate change thus could not be confirmed. This is attributed partly to the fact that poor yield years often can have positive effect on farm income due to increased crop prices in times of relative commodity shortages but can also be attributed to the fact that potato, sugar beet and winter wheat show different vulnerabilities with respect to weather conditions. Portfolio analysis appears to be therefore a suitable instrument for analysing effects of climate change at farm level.

Keywords

Portfolio analysis, climate change, crop growth models.

1 Introduction

The distribution of crop yield and quality usually are considered rather volatile due to a series of stochastic weather related factors determining crop growth. Primary crop production is directly affected via parameters such as CO_2 concentration, temperature and precipitation. The nature and character of these effects and reactions to specific conditions are crop specific and are strongly interrelated. Evidently, climate change will affect crop yield distribution and the interrelation between them. The impact of climate change is a function of the direction and average magnitude of changes in weather conditions as well as the impact of weather extremes. Projected general weather changes for northwest Europe are clear but their magnitude however is not. Warming is expected to increase both winter and summer seasons hence affecting production. Increased CO_2-concentrations directly enhance crop productivity while increasing water use efficiency. Changes of extreme weather events are more difficult to assess, but it must be stressed that such events are likely to increase both in frequency and extreme character. In severe cases, therefore, a substantial decline in farm income can be expected as a result of adverse weather conditions. The extent of this decline will depend on factors including crops cultivated, soil type (including texture, drainage), potentials for irrigation and risk behaviour.

The impact of changed risky prospects cannot be assessed without considering the potential impact on the whole portfolio of farm-specific risky prospects. Given the importance of weather conditions for crop yield, selection of a proper coping strategy for changing climate and weather conditions is essential. As incidence of weather-induced extremes is expected to increase, changes in crop management will be needed. While the precise effect on yield at this stage can not be determined, it is worthwhile to evaluate different types of adaptation measures that could be taken. The main question is to what extent expected changes can be compensated by minor adaptations such as changes in sowing date, cropping patterns, irrigation and other management factors, and to what extent major adaptations such as introducing new crops in the production plan are needed. In the current analysis vulnerability of farms with respect to income loss due to increased weather extremes is addressed by means of portfolio modelling. In the remainder of this paper, first possible climate change scenarios are outlined. Subsequently, joint yield distributions are generated by means of crop growth models. Finally the potential impact on the whole farm portfolio is discussed.

2 Materials and methods

One of the difficulties in portfolio analysis is to assess the joint distribution of cropping activities. In practice, yield data can be very sparse and with respect to climate change such data are unavailable. Future unobserved data can however be generated using crop growth models by means of imposing alternative climate change scenarios thus simulating changes that can be used to assess their effects on crop yields.

2.1 Climate change

Climate change scenarios for the Netherlands for temperature, precipitation, potential evaporation and wind for 2050 are derived from VAN DEN HURK et al. (2006). General Circulation Model (GCM) simulations which have become available during the preparation for the upcoming Fourth Assessment report (AR4) of IPCC were used to span a range of changes in seasonal mean temperature and precipitation over the Netherlands. It was found that most of this range could be related to changes in projected global mean temperature and changes in the strength of seasonal mean western component of the large scale atmospheric flow in the area around the Netherlands. Therefore, temperature and circulation were the main factors influencing for temperature, precipitation and potential evaporation. The construction of the extreme precipitation and temperature values and the potential evaporation values was carried out using an ensemble of Regional Climate Model (RCM) simulations and statistical downscaling on observed time series. Additional scaling and weighting rules were designed to generate RCM sub-ensembles matching the seasonal mean precipitation range suggested by the GCMs.

Future climatic conditions were simulated using weather files provided by the Royal Netherlands Meteorlogical Institute (Dutch acronym KNMI). Recently, KNMI generated new climate scenarios for 2020 and 2050 (VAN DEN HURK et al., 2006). Based on global climate models (GCM’s), regional climate models and historic measurement series, four scenarios were made with respect to assumptions on two of the most important factors that determine future weather (global temperature increase and changes in atmospheric circulation). Two scenarios assume a moderate temperature increase (+1^{o}C in 2050 in the moderate or ‘G’ scenarios), the other two assuming a stronger increase increase (+2^{o}C in the warm or ‘W’ scenarios). Likewise, changes in atmospheric circulation are assumed to be weak or strong (the latter being indicated by a ‘+’, thus identifying G, G+, W and W+ scenarios). Circulation has a great impact on the number of precipitation days, seasonal mean precipitation, extreme precipitation events as well as potential evaporation.

Scenario variables include summer (June to August) and winter (December to February) changes in mean temperature, mean temperature of yearly warmest / coldest day, mean precipitation, numer of precipitation days, mean precipitation on a precipitation day, 10-day precipitation sums exceeded every 10 years and summertime potential evaporation. Values were obtained from downscaling of CGM results for NW Europe, assuring that values for temperature change and circulation change represented underlying variabilities without overemphasizing extreme CGM projections. In our calculations, we restrict ourselves to the ‘G+’ scenario (i.e. assuming a moderate global temperature increase combined with a strong change in atmospheric circulation. Table 1 summarizes the climate change dataset analysed in the current paper. Temperature in The Netherlands continue to rise while mild winters and hot summers are becoming more common. On average, winters become wetter and extreme precipitation amounts will rise. The intensity of extreme rain showers in summer will increase, however, the number of rainy days in summer will decrease (VAN DEN HURK et al., 2006).

Crop growth calculations were done assuming a CO_2 level of 400 ppm, using daily mean, minimum and maximum temperatures as well as data on daily precipitation and potential evaporation as these were generated for the period of 2006-2035 (2020), as these were generated for a weather station (De Kooy) situated in the province of North Holland. More information on the background of the scenarios as well as the way they were generated is given at:
http://www.knmi.nl/klimaatscenarios/knmi06/gegevens/neerslag/index.html#Inhoud_1.

Table 1: KNMI’06 climate change G+ scenario.

parameter	time	descriptive statistics (average per year)						
		mean	std	CV	percentiles			
				%	10%	25%	75%	90%
minimum temperature	projected	7.32	0.85	11.54	6.05	6.83	8.04	8.36
(Celsius)	current	6.87	0.85	12.35	5.62	6.37	7.60	7.91
maximum temperature	projected	13.05	0.82	6.25	11.85	12.41	13.74	14.13
(Celsius)	current	12.59	0.82	6.51	11.39	11.97	13.30	13.68
precipitation	projected	2.21	0.36	16.22	1.71	1.89	2.44	2.61
(mm d-1)	current	2.18	0.35	16.15	1.68	1.85	2.39	2.59

Source: KNMI.

2.2 Crop growth models

Crop growth modelling calculations were done with WOFOST, a dynamic crop simulation model based on insight in physiological processes as determined by crop response to environmental conditions. Major processes considered include CO_2 assimilation, respiration, assimilate partition to plant organs, transpiration and phenological development. Solar radiation, temperature, water limitation and availability of nitrogen are major yield determining factors (WOLF AND VAN DIEPEN, 1993). The model is centered around the calculation of canopy photosynthesis and respiration based on processes at organ level. While operating with a time interval of one day, it allows for the diurnal course of radiation. Daily dry matter production is distributed to plant organs as a function of the developmental stage. Numerical integration over time give the time course of dry matter of various organs. The simulation covers the period from crop emergence to maturity (NONHEBEL, 1993).

WOFOST was developed for simulation of crop growth and development at field level in present climatic conditions. In order to simulate the effects of climate change and increase of CO_2 concentration on crop production adaptations were made to the original model following WOLF AND VAN DIEPEN (1991) and NONHEBEL (1993). Single leave response was modelled by increasing the maximum leaf assimilation rate as well as the initial angle of the so called light response curve (photosynthetic rate determined by CO_2 concentration). Further, the amount of leaf area per kg of leaf weight, expressed as Specific Leaf Area (SLA, $m^{-2}kg^{-1}$), was decreased at higher CO_2 concentrations. Reduced transpiration speed caused by increased CO_2 concentration could not be imposed on the available model and hence had to be ignored.

Calculations presented here refer to cultivation of potato, sugar beet and winter wheat on a deep sandy soil. Potatoes were irrigated with 162 mm. Fertilisation, date of sowing or planting and harvest are as close to practice as possible. The number of observations used in calculations varied due to differences in data availability and limitations in calculation time. A total of 29 years of weather data (1976 to 2004) were used for potato, while for sugar beet and wheat 10 years (1976 to 1985) were available. Crop yields after climate change were calculated using 30 simulated weather years for all crops.

2.3 Portfolio modeling

MARKOWITZ (1959) and the even earlier work of FREUND (1956) showed that quadratic risk programming (QRP) can be used to maximise the expected income of a risk-averse decision-maker subject to a set of resource and other constraints including a parametric constraint on the variance of income. The model can also be formulated to minimize the variance subject to a parametric constraint on expected income, or to expected CARA utility maximization with parametric variation in absolute risk aversion. All three should give identical solutions.

QRP restrictively uses the first two moments (i.e. mean and variance) of each risky activity and the first co-moment (i.e. covariance) between the risky activities. The obtained optimal portfolio with respect to income or wealth is usually held to be a reasonable approximation provided that the distribution of income or wealth is not very skewed. Note that the activity per unit net revenues may not have to be normal distributed for the distribution of income or wealth to be more or less normal. Under some particular assumptions, it is exact, e.g. when the distribution of income is normal and the utility function is negative exponential (FREUND, 1956) or when the utility function is quadratic (HARDAKER et al.).

As an alternative, a non-parametric risk-programming method is free of distribution assumptions and includes the joint distribution by means of so-called “states of nature” (i.e., specific combinations and probabilities of possible outcomes). Utility-efficient programming (UEP) is one of the non-parametric methods applied in farm portfolio analysis. The UEP for the case farm was formulated as follows:

$$\max E[U] = p\ U(z,r),\ r \text{ varied,} \tag{1}$$

subject to:

$$Ax \leq b \tag{2}$$

$$Cx - Iz = f \tag{3}$$

$$x \geq 0 \tag{4}$$

where: $E[U]$ is expected utility, p is vector of probabilities for states of nature, $U(z,r)$ is a vector of utilities of net income where the utility function is defined for a measure of risk aversion, r, A is a matrix of technical coefficient, x is a vector of activity levels, b is a vector of resource stocks, C is a matrix of gross margins for S states of nature, I is a identity matrix, z is a vector of net incomes for each state of nature S, f is a vector of fixed costs. Because we assume that the farmer is risk-averse, we are restricted to using a concave form of the utility function with $U'(z) > 0$, and $U''(z) < 0$. Although in principle any kind of utility function can be used, in the current research the negative exponential function is used.

It is assumed that all states of nature are equi-probable. For simplicity, we also assume that the farmer’s relative risk aversion with respect to wealth rr(w) = 2, implying rather strong risk aversion. Utility and risk aversion are in the current research measured in terms of transitory income. The level of the farmer’s wealth (net assets), w, is assumed to be 1,000,000 Euro, so a value of = 2/1,000,000 = 0.000002 was used as the farmer’s degree of absolute risk in this analysis.

Some normative assumptions were made in order to formulate the whole-farm model. A typical Dutch arable farm was selected as case farm. Farm size was 50 hectares and cropping plan comprised potatoes, sugar beet and winter wheat. A rotational restriction was imposed so that all kinds of potato would not exceed one-fourth of the total area. The maximum amount of sugar beet was set at 10 hectares. Cereal crops (in this case only winter wheat) were unrestricted.

Generated crop yields with the WOFOST model were utilised to construct the states of nature of gross margin per crop. The input data concerning farm business and financial structure as well as stochastic dependency between yields and prices were obtained from the Farm Accounting Data Network (FADN) data set. The UEP model was solved using GAMS/CONOPT3.

3 Results

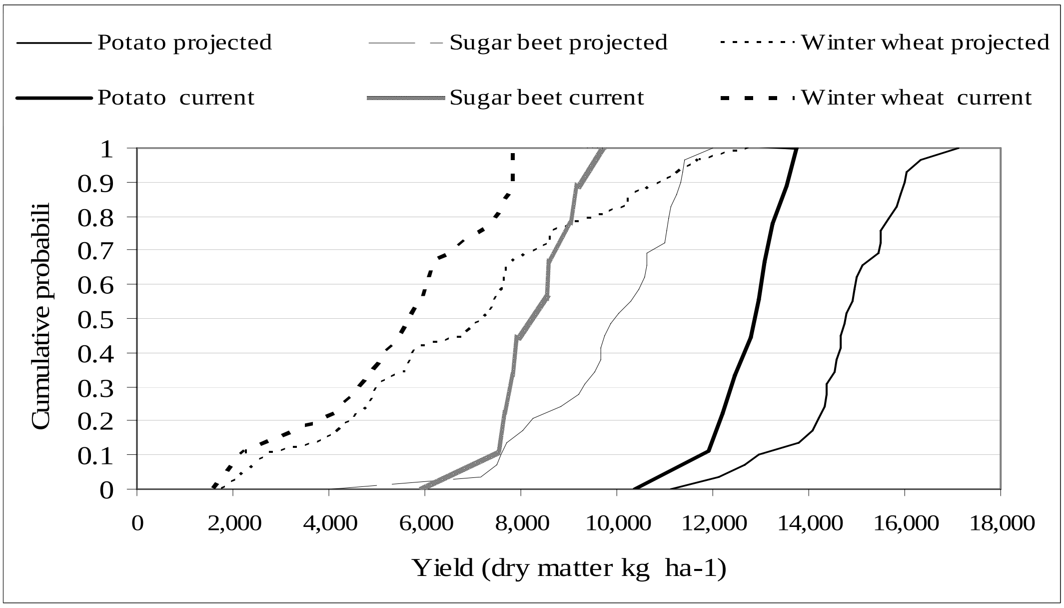
3.1 Crop yield distributions

Generated yield distributions are presented in Table 2 and Figure 1. Future yields increased for all crops due to more favourable average weather conditions (temperature and CO_2 concentrations). Increased temperatures refer to the periods of crop growth while increased CO_2-concentrations directly enhance crop productivity. Highest absolute yield increases are found in potato while winter wheat shows highest relative increases. In all cases, yield variance increases. Increased yield variability is also depicted in Figure 1.

Table 2: Current and projected crop yields.

crop	time	descriptive statistics						
		mean	std	CV	percentiles (dry matter kg/ha)			
		kg/ha	kg/ha	%	10%	25%	75%	90%
potato	projected	14,716	1,264	8.59	12,912	14,341	15,511	16,018
potato	current	12,636	978	7.74	11,751	12,278	13,223	13,555
sugar beet	projected	9,681	1,715	17.72	7,565	8,912	11,037	11,350
sugar beet	current	8,212	1,072	13.06	7,397	7,712	8,940	9,243
winter wheat	projected	6,899	2,988	43.30	2,643	4,851	8,642	10,981
winter wheat	current	5,347	2,190	40.96	2,175	4,328	7,121	7,824

Figure 1: Current and projected CDF's of crop yields.



3.2 Impact on whole-farm level

The input data concerning prices were obtained from the FADN data set. The expected price levels for potatoes, sugar beet and winter wheat used were 0.09, 0.05 and 0.12 Euro per kg respectively. The CVs of prices were widely dispersed; with extremely low values for sugar beet (3%) and extremely high values for potato (44%), while the CV for winter wheat amounted 10%. Moreover, FADN records demonstrates an inverse relation between yield and crop prices. On the whole, winter wheat had the lowest correlation values compared to the other crops (-0.05). The yield-price correlation values of other crops varied from the lowest value, for sugar beet (-0.30), to the highest value for potato (-0.40). The inverse relation can be explained by the fact that decreased crop yields are associated with an increment in their respective prices and vice versa. The fact that cereals are more a commodity in comparison to for example (table and seed) potatoes explains the low correlation between yield and price observed at the local Dutch market (cereals are produced globally and the total volume produced is therefore less volatile, moreover it is shipped worldwide and thus decreasing local price volatility).

Simulated yield matrixes obtained from the crop growth models subsequently were merged with a price matrix to represent the states of nature matrixes of gross margins incorporated in the UEP model. Crop prices were simulated via Monte Carlo simulation and merged with the yield matrixes in such way that they mimicked the joint distributions as observed in the FADN records. From the derived revenues per crop per state variable costs were subtracted (comprising costs for among others seed, fertilisers, pesticides and harvesting) while applicable subsidies were added to obtain gross margins. Subsequently, fixed costs were taken into account in the UEP model (75,000 Euro). Note that the matrix representing the projected situation did not take into account altered CAP arrangements (which will likely have its impact on subsidies received as well as price levels and price volatilities).

The optimisation procedure with the two states of nature matrixes generated almost identical optimal production plans for the two situations. The optimal production plans were hardly affected by the level of risk aversion. In the optimal production plan the amount of potatoes and sugar beet equalled the imposed (maximum) constraint levels, while winter wheat supplemented the production plan to utilise all land available. This portfolio is common practise since potatoes and sugar beet are considered as cash crops in Dutch arable farming.

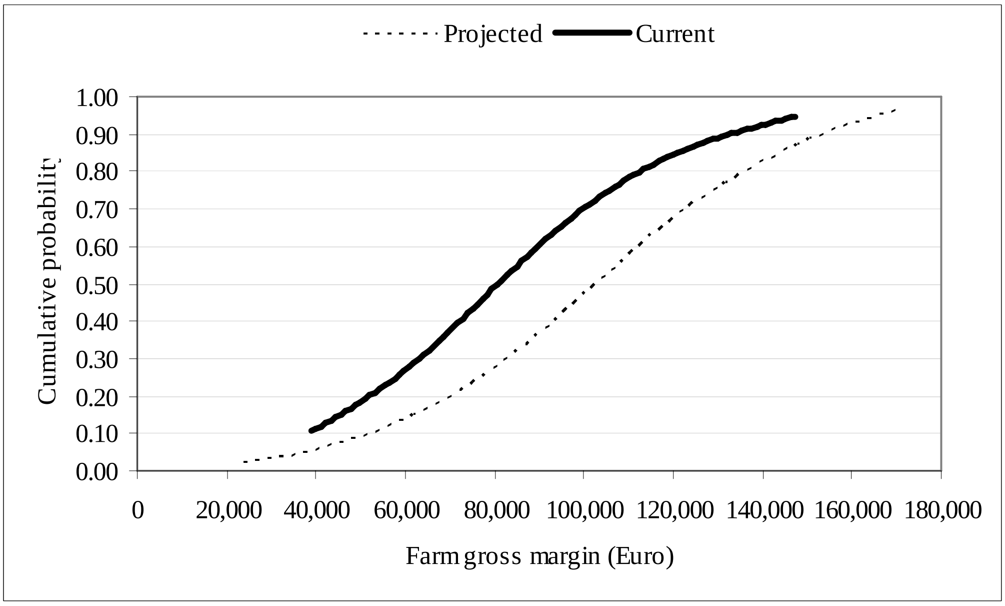
Differences in farm results (i.e., revenues, gross margin, farm income and certainty equivalents) were mainly the result of yield differences. Since projected yields were higher than current yields the projected farm results outperformed the current farm results (Table 3). Note that gross margins at whole farm level are presented since fix costs differ substantially between farms. Given a farm size of 50 hectares the results imply that the expected gross margin improves with approximately 400 Euros per hectare. The CV decreased although the standard deviation increased but this was offset by the increment of the expected level.

Table 3 Current and projected farm gross margins.

time	descriptive statistics (farm gross margin)						
	mean	std	CV	percentiles (Euro)			
	Euro	Euro	%	10%	25%	75%	90%
projected	102,721	34,592	33.68	58,275	78,019	122,986	149,907
current	83,100	33,581	40.41	39,366	67,390	101,584	118,600

The cumulative probability distributions presented in Figure 2 are obtained via a Kernell density smoothing procedure. Instead of minimizing the sum of squared residuals to smooth the states of nature of the optimal farm plan, the kernel density estimation method weights states based on relative proximity to estimate a probability (the Gaussian kernel was used with SIMETAR). As can be seen in the figure the projected CDF dominates the current CDF of gross margin in the presented domain (0.10% percentile up to 95% percentile).

Figure 2 **Current and projected CDF's of farm gross margins.**



4 Conclusions and discussion

The potential impact of climate change on crop production in The Netherlands was explored at farm level by means of a whole farm portfolio analysis. Projected joint crop yield distributions were derived from the WOFOST crop model, comparing production under simulated weather conditions with calculations based on historical weather data. This allowed to analyse effects of climate change for a typical Dutch arable farm with potatoes, sugar beet and winter wheat on a sandy soil in the north of the country. Future crop yields and, ultimately, farm income are expected to increase due to more favourable climate conditions.

Although the method used in the paper produced useful and detailed insight into the prospective impact of climate change at the whole farm level, it has a few limitations. The optimal production plan was hardly sensitive to the sets of yields. This may not be surprising since the portfolio model used is rather simple including only three crops and limited number of technical constraints imposed. More activities and constraints will generally give more differences to the solutions in the region of the optimum, however it is unlikely that this will alter the general conclusion.

Although for the projected climate change 30 probable outcomes were generated it is unlikely that catastrophic events are captured adequately. Changes with respect to extremes are expected, mainly the frequency of excessive rainfall and droughts, these were not a specific subject of this study. The presented tails of the distribution are therefore less robust, this holds for adverse outcomes but also for more favourable outcomes. However, the middle of the distribution will be estimated adequately given the reasonable number of states of nature generated. As a result the optimal production plan and corresponding difference observed in farm outcomes between the current and projected farm results are believed to be robust.

In our calculations we have not included the expected effect of increased CO2 concentrations on water use efficiency. If this is to be included in the calculations, it is expected that yield increases are higher for all crops while differences between 'dry' and other years on crop yields may be mitigated. Hence, the frequency of extreme low yields due to low precipitation is to be reduced. Further, we have allowed irrigation only for potato. If this is to be extended to sugar beet and winter wheat, yield variability for these crops is expected to be reduced.

Important factor determining the outcome of the calculations is the price relation between yield and price level. This has been based on historical information but it is not clear whether a similar relation can be expected for the future. General trend currently is showing an increased demand for agricultural commodities, especially cereals but also sugar crops. This is partly explained by increased demand for animal products (caused by intensive economic growth in countries like China and in the near future possibly India), combined with increased production variability and risk of crop failure (drought in countries like Australia and Russia) and sharp rising demand for bio-energy crops.

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